Equation Based Heat and Mass Transfer in Porous Media

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Abstract

Introduction

An essential part of human thermoregulation is perspiration during intense physical activity. The clothing that covers the body affects the cooling rate of the body. Since both heat and water vapor are coupled through evaporation and transported through the fabric, an accurate model of such a system can provide better understanding to human cooling. By using COMSOL Multiphysics® with its PDE solver a model of the above system can be developed for fabrics of different properties to simulate human cooling.

Use of COMSOL Multiphysics

To have complete coupling of the physics involved and the freedom to manipulate the model, the PDE solver was used to model the problem. Therefore, each governing equation was put into the Coefficient or General Form for the two-dimensional geometry shown in Figure 1.

First the continuity and incompressible Navier-Stokes equations were modeled using an artificial compressibility to solve for the pressure field. This artificial compressibility is generally given by Chorin (1967) as

$\partial p/\partial t+\nabla\cdot(rho\_g\ u\_g)=0$

where u_g is mixture velocity vector with components u and v. In COMSOL pressure is declared as a dependent variable with the general form PDE and the continuity equation for incompressible steady flow becomes a mass source for the pressure equation written as

$\partial p/\partial t= -rho\_g\ (\partial u/\partial x+\partial v/\partial y)$.

For a steady solution this mass source is annihilated when the velocity field is solved for.

Inside of the porous medium (PM) there is convection and a momentum equation for the PM. It is given by the equation used by COMSOL for a free and porous medium flow situation.

Currently, to simulate evaporation a temperature dependent water vapor boundary condition (BC)

is imposed. This BC uses the saturation vapor pressure at temperature T (Kelvin) to determine the vapor density by

rho_v (T)= (p_sat (T)M)/RT

where the saturation pressure is given by Charmchi (1997) as

p_sat (T)=614.3 exp[17.06((T-273.15)/(T-40.25))]

where M is the molecular weight of water and R is the universal gas constant. Coupled to vapor density is the energy associated with it. The heat transferred to the vapor during evaporation is accounted for by the latent heat of vaporization through a 'conservative flux source' term in the energy equation, given as ∇·(L rho_v u_v).

Results

For the case of no liquid water and steady state, the temperature field is affected by the vapor density as desired. To show this more clearly the vapor density was scaled by a factor of 100 and plots for the scaled and un-scaled cases are shown in Figure 2. When the vapor density is increased more energy is present through the conservative flux source term.

Conclusion

Equation-based modeling allows the researcher to fully couple and manipulate the physics they desire as demonstrated above. Because of that, steps are being taken to model drying at a liquid-vapor interface in the PM when a liquid state is present. Doing so would incorporate the majority of physics involved in heat and mass transport in fabrics leading to a better understanding these fabric have on human thermoregulation.

Reference

1. Majid Charmchi and Phillip Gibson, Modeling Convection/Diffusion Processes in Porous Textiles with Inclusion of Humidity-Dependent Air Permeability. International Communications in Heat and Mass Transfer, 24(5), 709-724 (1997)

2. Alexandre Chorin, A Numerical Method for Solving Incompressible Viscous Flow Problems. Journal of Compuatational Physics, 2, 12-26 (1967)

3. COMSOL Multiphysics. (n.d.). COMSOL Multiphysics User's Guide.

Figures used in the abstract

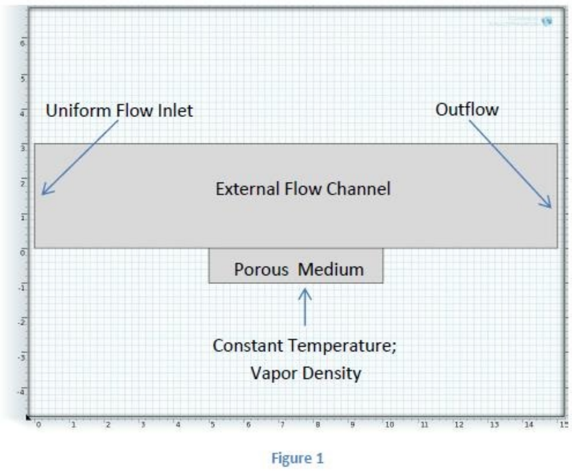

Figure 1

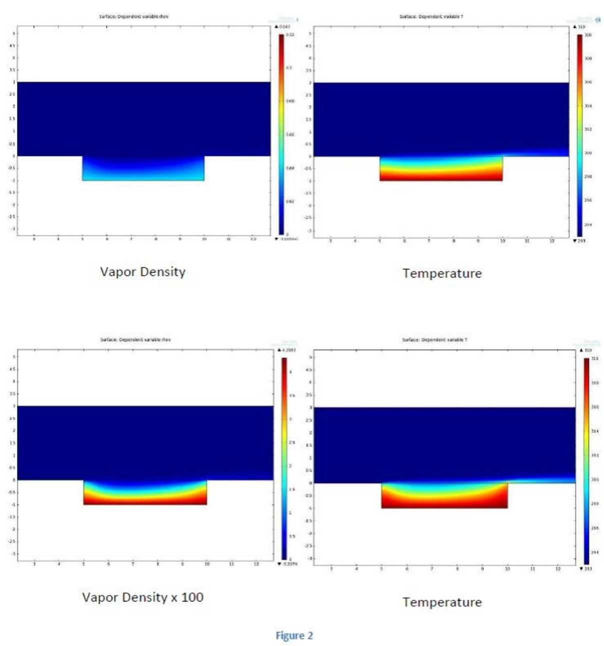

Figure 2